Canonical Strangeness Enhancement*

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According to recent experimental data and theoretical developments we discuss three distinct topics related to strangeness enhancement in nuclear reactions. We investigate the compatibility of multi-strange particle ratios measured in a restricted phase space with thermal model parameters extracted recently in 4π. We study the canonical suppression as a possible reason for the observed strangeness enhancement and argue that a connection between QGP formation and the undersaturation of strangeness is not excluded.

1. Multi-strange hadrons from thermal models

Particle production in heavy ion collisions at SPS energies has been recently analyzed in [1]. The analysis includes particle abundances and ratios measured or extrapolated to full momentum space. The use of 4π data makes the analysis independent of the particle momentum distributions which are quite different from the ones of a static fireball. In order to test the significance of the results derived in [1] we investigate its compatibility with multi-strange baryon ratios omitted in [1] due to their measurements in limited phase space. In order to cut the thermal model prediction for these ratios to the experimental acceptance we define an acceptance correction factor C_r for each considered particle ratio r by the ratio

$$C_r = \frac{N^{\rm acc}}{N^{4\pi}} \ . \tag{1}$$

In order to calculate C_r we use the momentum distributions of Λ's, Ξ's and Ω's as they result from the hydrodynamical evolution of the corresponding collision [2]. It has been shown [2] that this evolution scenario describes quite well the momentum distributions of various hadron species.

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Table 1
Comparison of (multi-)strange particle ratios with the thermal model. The kinematic cuts applied are $2.5 < y < 3.0$, $1.2 < p_T < 3.0$ (S+S [3]), $2.3 < y < 3.0$, $1.2 < p_T < 3.0$ (S+W [4]), and $2.4 < y < 3.4$, $0.7 < p_T$ (Pb+Pb [5]).

	WA94 S + S 200 A GeV		WA85 S + W 200 A GeV	
ratio	experiment [3]	thermal model	experiment [4]	thermal model
$\overline{\Lambda}/\Lambda$	0.23 ± 0.01	0.176 ± 0.017	0.196 ± 0.011	0.156 ± 0.015
$\overline{\Xi}/\Xi$	0.55 ± 0.07	0.327 ± 0.046	0.47 ± 0.06	0.303 ± 0.042
Ξ/Λ	0.09 ± 0.01	0.124 ± 0.009	0.097 ± 0.006	0.120 ± 0.009
$\overline{\Xi}/\overline{\Lambda}$	0.21 ± 0.02	0.231 ± 0.023	0.23 ± 0.02	0.228 ± 0.022
	WA97 Pb + Pb 158 A GeV			
ratio	experiment [5]	thermal model		
$\overline{\Lambda}/\Lambda$	0.124 ± 0.013	0.179 ± 0.017		
$\overline{\Xi}/\Xi$	0.255 ± 0.025	0.328 ± 0.045		
$\overline{\Omega}/\Omega$	0.38 ± 0.10	0.61 ± 0.12		
Ξ/Λ	0.099 ± 0.008	0.100 ± 0.007		
$\overline{\Xi}/\overline{\Lambda}$	0.203 ± 0.024	0.184 ± 0.018		
Ω/Ξ	0.192 ± 0.024	0.126 ± 0.011		

The analysis presented in [1] shows that the intensive thermal parameters are insensitive to the nuclear collision size. At SPS energies hadronization can then be characterized by a universal set of parameters $T = 180 \pm 10$ MeV, $\gamma_s = 0.7 \pm 0.05$ and $\mu_{\mathrm{B}}/T = 1.25 \pm 0.1$. Taking these values as input for a thermal model calculation and multiplying the resulting ratios with C_r of Eq. (1) we get the results shown in Table 1. They are in agreement with the measurements of WA94 [3], WA85 [4] and WA97 [5] within 2–3 standard deviations. Taking into account the model uncertainties in the acceptance corrections we find that also the multi-strange baryons are compatible with an undersaturation of strangeness of order $\gamma_s = 0.7 \pm 0.05$.

2. Canonical strangeness enhancement

Various experiments report an enhancement of strange to non-strange particle ratios going from p+p to A+A collisions [5,7]. On the other hand, in a thermal model the strange hadrons are suppressed by exact conservation of quantum numbers when going from large volumes (A+A collisions) to small ones (p+p collisions). The immediate question is whether the canonical suppression can account for the observed effect. Since the γ_s values for p+p collisions $\gamma_s = 0.5 \pm 0.05$ [6] and for A+A collisions $\gamma_s = 0.7 \pm 0.05$ [1] are clearly different while the hadronization temperature $T = 180 \pm 10$ MeV is rather universal the volume increase is not the only effect which accounts for the total strangeness enhancement. This is shown quantitatively in Figure 1 where the ratios K_s^0/h^- and $E_S = (\langle\Lambda\rangle + \langle K\rangle)/\langle\pi\rangle$ are shown as function of participating baryons B_{part}. Taking the volume per participating baryon as $V_0 = V/B_{\mathrm{part}} = 5$ fm^3, a value which is also in agreement with the total abundances, then we find that the canonical suppression accounts only for half of the observed effect.

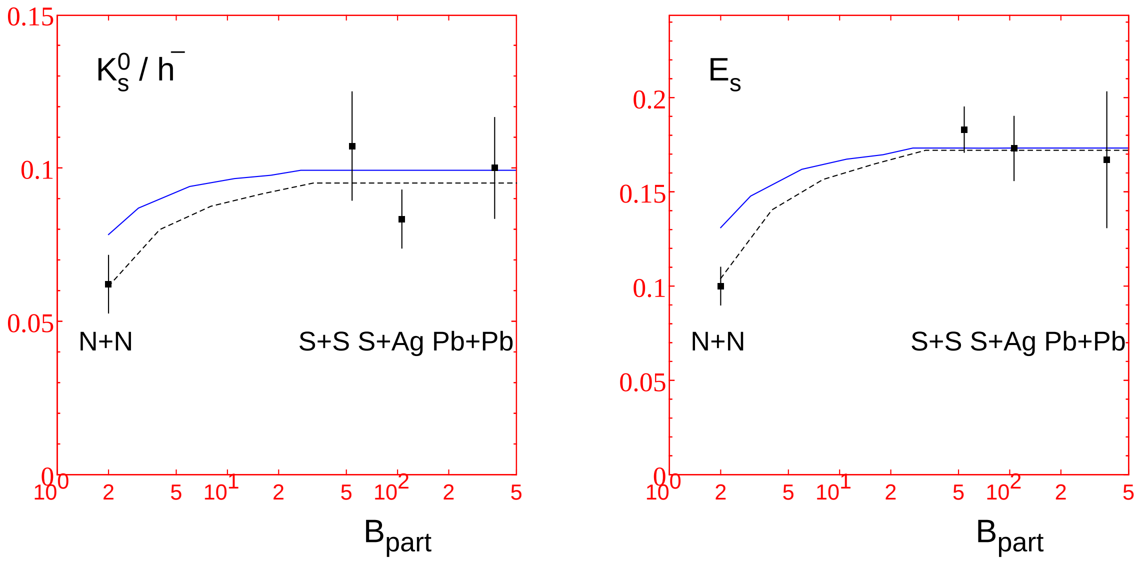

Figure 1. K_s^0/h^- and E_S as function of $B_{\rm part}$ in a thermal model with $T = 180$ MeV and $\gamma_s = 0.7$. The volume V is $V = 5$ fm$^3 \times B_{\rm part}$ (solid line) and $V = 2.5$ fm$^3 \times B_{\rm part}$ (dashed line). The data for E_S are taken from the compilation in [7] and for K_s^0/h^- from the compilation in [1] and [8] (N+N, i.e. isospin averaged nucleon nucleon collision).

On the other hand, if we take only one half of the original volume, i.e. $V_0/B_{\rm part} = 2.5$ fm^3, then the strangeness enhancement in particle ratios can be accounted for by the canonical suppression alone (see Figure 1, dashed line). One gets $\gamma_s \approx 0.7$ for p+p collisions as also seen in e^++e^- [9] and in A+A [1] collisions. This would imply universality of γ_s. In order to get the proper values of the total particle abundances in such a scenario at least two small fireballs are required which have to hadronize independently. E.g. for p+p collisions a model with two fireballs associated to the leading protons may be constructed. However, this suggestion suffers from a serious difficulty connected with the measured ϕ yield. The ϕ-meson is not canonically suppressed because it has zero charges. For $\gamma_s \approx 0.7$ in p+p collisions the measured ϕ abundance deviates from a thermal fit by 12σ, increasing even more the already troublesome deviation of 4σ for $\gamma_s = 0.5$ [6].

3. Saturation of γ_s

In order to understand the systematics of hadron production it is important to look at the A-scaling of γ_s. It was found [1] that the chemical freeze-out in nuclear collisions at CERN-SPS appears with rather constant $\gamma_s = 0.7 \pm 0.05$. This result suggests that undersaturation of strangeness is independent of the system's size and the life time of the fireball. We now present an argument [10] for a possible explanation of the apparent A-independence of γ_s in nuclear collisions. Let us consider the ratio $r_S = \langle s+\overline{s}\rangle/S$ of the total number of strange quarks $\langle s+\overline{s}\rangle$ over total entropy S. Since the ratio $r_S^{\rm QGP}/r_S^{\rm HG}$ is of the same order as the afore mentioned undersaturation of strangeness it is conceivable

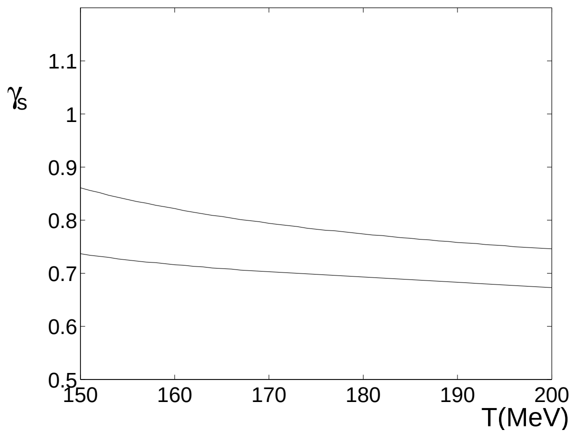

Figure 2. γ_s of the hadron gas which gives the same strange quark multiplicity per entropy as a fully equilibrated quark-gluon plasma at the same temperature. The net baryon number was set to zero. The upper line is for a strange quark mass of $m_s = 130$ MeV, the lower line for $m_s = 190$ MeV.

that at high bombarding energies the value of γ_s could be determined by $\gamma_s \approx r_S^{\rm QGP}/r_S^{\rm HG}$. Since $r_S^{\rm HG}$ depends on γ_s in a non-linear way we solve the implicit equation [12]

$$r_S^{\rm QGP}(T, S/A) = r_S^{\rm HG}(T, S/A, \gamma_s) \tag{2}$$

for γ_s. The formulation of the hadron gas thermodynamics is done as in [1] while for the QGP an ideal non-interacting parton gas with two massless flavours and a massive strange quark with $m_s = 160 \pm 30$ MeV [11] is used. For zero baryon density we get the results shown in Figure 2. In the temperature range expected for the deconfinement transition the resulting γ_s is of the same order as the one extracted in the chemical analysis for particle abundances [1]. For finite baryon densities the results do not change [12] qualitatively.

The hadronization of gluons from a QGP will naturally also feed into the strange sector. If this branching of gluons is large the whole idea can only be rescued by assuming that in the hadronization process a similar increase in entropy is present. Since these processes lie in the non-perturbative domain of QCD a quantitative treatment is out of sight. The principal possibility, however, that the observed undersaturation of strangeness might be due to the hadronization of a partonic gas cannot be excluded.

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